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AN ANALYTICAL INVESTIGATION OF THE EFFECT OF VARYING ROTOR TIP SPEED TO REDUCE HELICOPTER ACOUSTIC DETECTION

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August 1979

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The purpose of this study was to analytically determine the effect of incrementally varying helicopter rotor tip speed to decrease noise levels and detection distance. The basis for this study was that primary mission performance (PMP) would be maintained at each incremental change of rotor tip speed.

A baseline helicopter was designed that met the Advanced Scout Helicopter (ASH) PMP requirements. It used a 700-fps tip speed four-bladed rotor system. Four generic configurations of the

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baseline helicopter were also designed which met the PMP requirements. The design rotor tip speed of these configurations varied to 105, 95, 90, and 80 percent of the baseline tip speed.

Overall sound pressure levels (OASPL), 1/3 octave band spectra, and detection distances were predicted for all helicopter configurations for a range of operational speeds.

Results showed that the 90-percent (630 fps) tip speed configuration was optimum in terms of reduced OASPL. When all configurations were analytically displaced in distance to the point at which their noise signature could first be perceived, the 100-percent (700 fps) tip speed configuration was least detectable. It was also found that OASPL was not a reliable indicator of detectability and that ambient noise conditions had the largest net effect on detectability.

PREFACE

This report presents the results of an analytical investigation to evaluate the effects of variable rotor speeds on helicopter noise detection.

Appreciation is given to Mr. Robert J. Pegg of the Acoustics and Noise Reduction Division, NASA-Langley Research Center, for his assistance in performing the Theoretical Rotor Analysis Modeling Program (TRAMP) calculations used in this effort.

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INTRODUCTION

To maximize helicopter survivability through reduced aural detection distance, the aircraft designer first considers reducing main rotor tip speed as one of the fundamental methods for reducing rotary-wing noise levels. It is generally agreed that changes in main rotor tip speed have the greatest influence on helicopter noise and detection distance; this is illustrated in Figure 1 (from Reference 1). In this example, total rotor thrust and blade loadings were held constant by chord variations. The standard case parameters produced a single value for detection distance. Variation of any one of these parameters produced a different detection distance, as shown by the trend curves. The most noticeable result seen in Figure 1 is the effect of blade tip speed on detectability, particularly above 600 fps. Data from whirl tower testing by Hubbard and Maglieri[2] derived over a range of normal functional rotor speeds produced 0.04 dB reduction in noise for each fps reduction in tip speed. The ARPA "Quiet One" helicopter[3] was measured at 0.08 dB/fps tip speed reduction, while a standard OH-6 measured 0.064 dB/fps tip speed reduction. Thus, whether theoretical or measured data is used, lowering tip speed indicates that this is clearly a first choice approach to reducing levels of noise and acoustic detection.

However, an important point that must be considered before the worth of this approach can be properly evaluated is the effect of varying tip speeds on an aircraft while maintaining imposed performance requirements. For example, reduced rotor tip speed necessitates that thrust be recovered through other means that may require heavier engines and transmissions, more fuel, and stronger airframes, all of which would affect mission performance. Thus the full problem becomes one of optimizing tip speed with detectability and performance.

The purpose of this investigation was to analytically determine the optimum effect of incrementally varying helicopter rotor tip speed on decreased noise levels and detection distance, while maintaining primary mission performance (PMP) requirements for each increment of rotor speed variation.

To carry out this investigation, a baseline helicopter design was developed which met the primary mission performance (PMP) requirements of the Advanced Scout Helicopter (ASH) specification.[4] A nominal tip speed of both the main and the tail rotors was established based on rotor performance and efficiencies. Next, four alternate design configurations,

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[1] Ollerhead, J. B., and Lowson, M. V., *Problems of Helicopter Noise Estimation and Reduction*, AIAA Paper No. 69-195, Wyle Laboratories, Huntsville, Alabama, February 1969.

[2] Hubbard, H. H., and Maglieri, D. J., *Noise Characteristics of Helicopter Rotors at Tip Speeds Up to 900 Feet Per Second*, Journal of the Acoustical Society of America, Volume 32, No. 9, September 1960, pp 1105-1107.

[3] Robinson, Frank, *Component Noise Variables of a Light Observation Helicopter*, NASA CR 114761, Ames Directorate, U.S. Army Air Mobility Research and Development Laboratory, Ames Research Center, Moffett Field, California, 1975.

[4] ASH Solicitation DAAJ01-76-R-0001, 31 July 1975, USAAVSCOM (Unpublished).

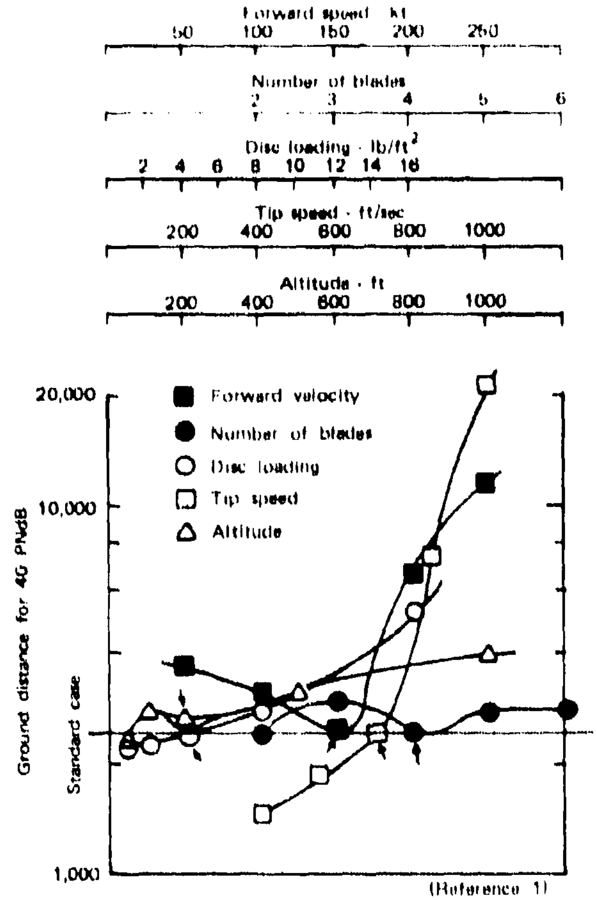

Figure 1. Effects of various rotor and flight parameters on "detection range".

each maintaining PMP requirements, were developed. The main and tail rotor tip speeds of these configurations were incrementally varied from the baseline tip speed. Throughout this report these designs will be referred to simply as the 105-percent configuration, the 100 percent configuration, etc.

An acoustical prediction of the rotor system noise signatures was made using the five configurations at hover and at flight speeds of 80, 120, and 150 knots. The noise matrix consisted of the five configurations times four flight speeds times three rotor combinations (main rotor, tail rotor, and main plus tail rotor). Noise levels and detection distance versus rotor tip speed were plotted for each flight speed. From these results, conclusions and recommendations were made concerning varying rotor tip speed as a means of reducing acoustic noise/detection distance.

BASELINE AND ALTERNATE DESIGN CONFIGURATIONS

The baseline and alternate configurations were designed to meet the PMP requirements of the Advanced Scout Helicopter specification. These requirements are summarized in Appendix A. The characteristics of the baseline and alternate configurations are compared in Table 1.

TABLE 1. CHARACTERISTICS OF BASELINE HELICOPTER AND ALTERNATE CONFIGURATIONS

	105 Percent	Baseline	95 Percent	90 Percent	80 Percent
Main Rotor					
Tip speed (fps)	735	700	665	630	560
Disc loading (psf)	7	7	7	7	7
Radius (ft)	16.04	16.11	16.23	16.41	16.95
Solidity	0.0896	0.099	0.1108	0.1247	0.1638
Tail Rotor					
Tip speed (fps)	735	700	665	630	560
Radius (ft)	3.07	3.16	3.26	3.38	3.73
Engine Rating (hp)	603	605	614	629	679
Transmission Limit (hp)	1027	1032	1046	1072	1157
Weight Summary (lb)					
Structure	1320	1353	1397	1456	1627
Propulsion	1107	1131	1167	1217	1369
Flight controls	218	219	221	223	232
Equipment	688	688	688	690	692
Empty Weight	3333	3391	3473	3686	3920
Crew	470	470	470	470	470
Fluids	28	28	28	28	30
Mission Fuel	1001	998	1000	1016	1076
Payload	823	823	823	823	823
Gross Weight	5665	5708	5794	5922	6318

BASELINE CONFIGURATION

The baseline configuration was developed using the Applied Technology Laboratory's Preliminary Design Program (PDP). It used a conventional four bladed main/tail rotor system powered by two advanced technology engines. Conceptual views of the baseline design are shown in Figures 2 and 3. The four-bladed main rotor was fully articulated, with a disc loading of 7 psf and a tip speed of 700 fps. It had a solidity of 0.099, defined by the 1.50g maneuver requirement, a 12 degree linear twist, and an advanced 9.5-percent-thick airfoil section which was the same as that used on the UH-60A Black Hawk. The tail rotor, sized by the vertical climb condition, also had four blades and a tip speed of 700 fps. The two engines were mounted in a semi-podded configuration on the upper fuselage. They were sized with 95 percent intermediate power available matched to power required for 450 fpm vertical rate of climb at design gross weight at 400 ft, 95°F. Both intake particle separators and infrared suppression devices were installed in the engines. Starting was by battery or external power source.

The main transmission combined the inputs from the engines with power takeoffs for the antitorque rotor drive and accessories. The continuous rating of the main transmission was 125 percent of the power required for 450 fpm vertical rate of climb at design gross weight at 4000 ft, 95°F, with each input section capable of transmitting single-engine uninstalled intermediate rated power available at sea level, standard day condition. The fuel system was crashworthy and self sealing against 7.62mm threats.

The airframe structure was primarily conventional semi-monocoque aluminum, with limited use of composite materials in selected primary and secondary structures. For weight scaling, structural technology was assumed to be equivalent to the UH-60A Black Hawk. The cockpit section accommodated a crew of two, seated laterally in armored, crashworthy seats. Both crew members were provided with instrumentation necessary to accomplish all weather NOE flight, and both could monitor most sensor readouts. Crew entrance doors were located on each side of the cockpit, and windshield and window panels were flat to reduce detectability due to sun glint. Bays for sensors and avionics equipment were located in the nose, above the fuel tanks aft of the cockpit, and aft of the fuel tank bay. Weight increments for crashworthiness and maintainability considerations were included.

A nonretractable, tricycle landing gear configuration with high energy attenuation capability was used.

The mission equipment load was 823 pounds, which included a target acquisition system; the pilot's night vision system; and portions of the communications, navigation, instrumentation, security, and ASE equipment groups.

ALTERNATE CONFIGURATIONS

Sizing variations for the alternate designs were also developed using the Applied Technology Laboratory's Preliminary Design Program (PDP).

A four bladed main rotor with a disc loading of 7 psf was retained for all alternate configurations. The baseline twist and airfoil section were also retained for all configurations, while solidity was varied such that a nearly linear variation of C_T resulted as a

function of tip speed. Main and tail rotor tip speeds were arbitrarily varied together for all configurations, and tail rotor size was varied as necessary to balance the main rotor torque. Engine and drive system ratings were varied as required to maintain the performance capability of the baseline configuration. The fuselage envelope scaling was limited to the tail boom length and the engine and main transmission cowlings. The physical appearance of the alternate aircraft configurations was nearly the same as that of the baseline.

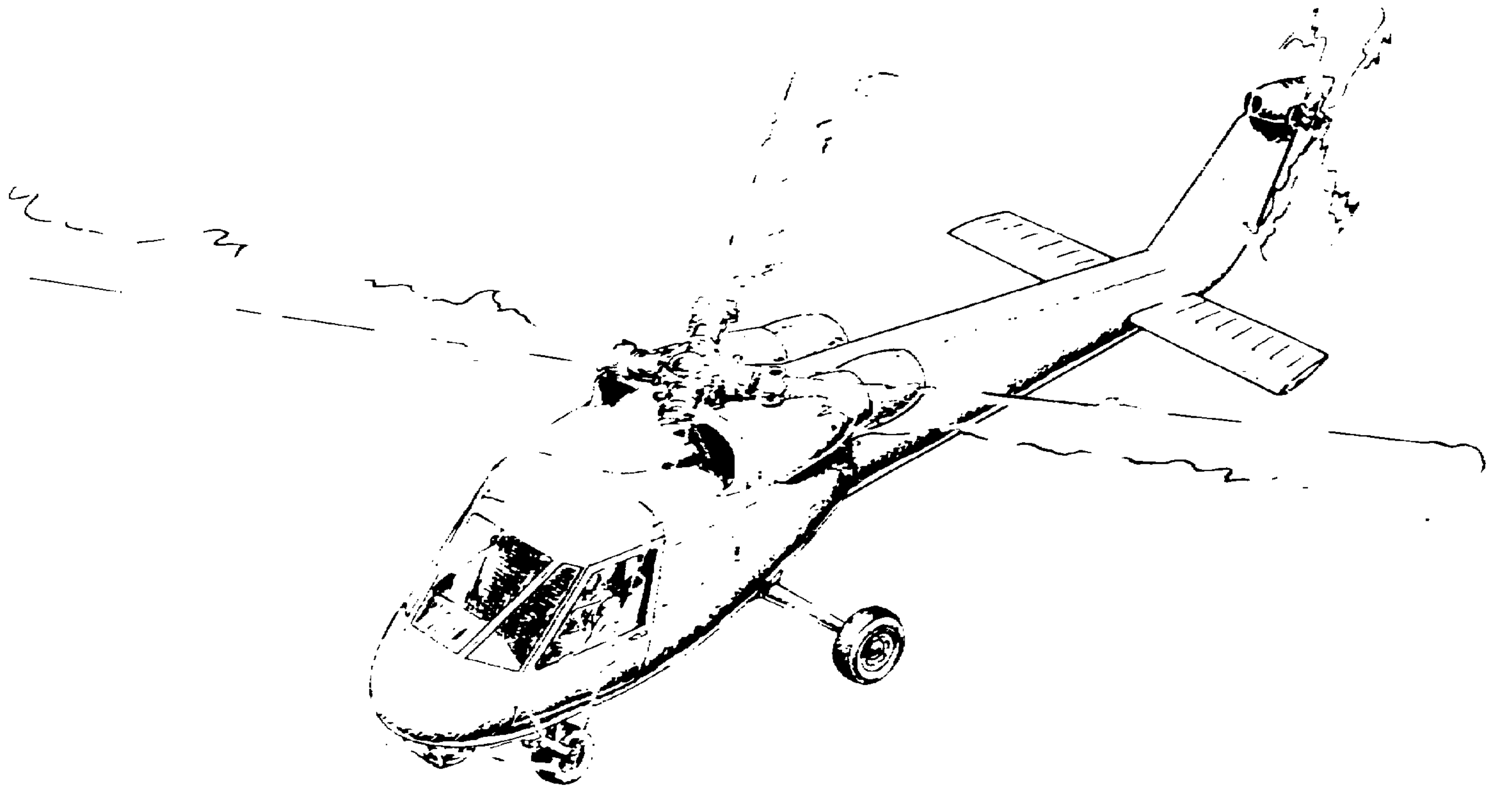

Figure 2. Baseline helicopter configuration.

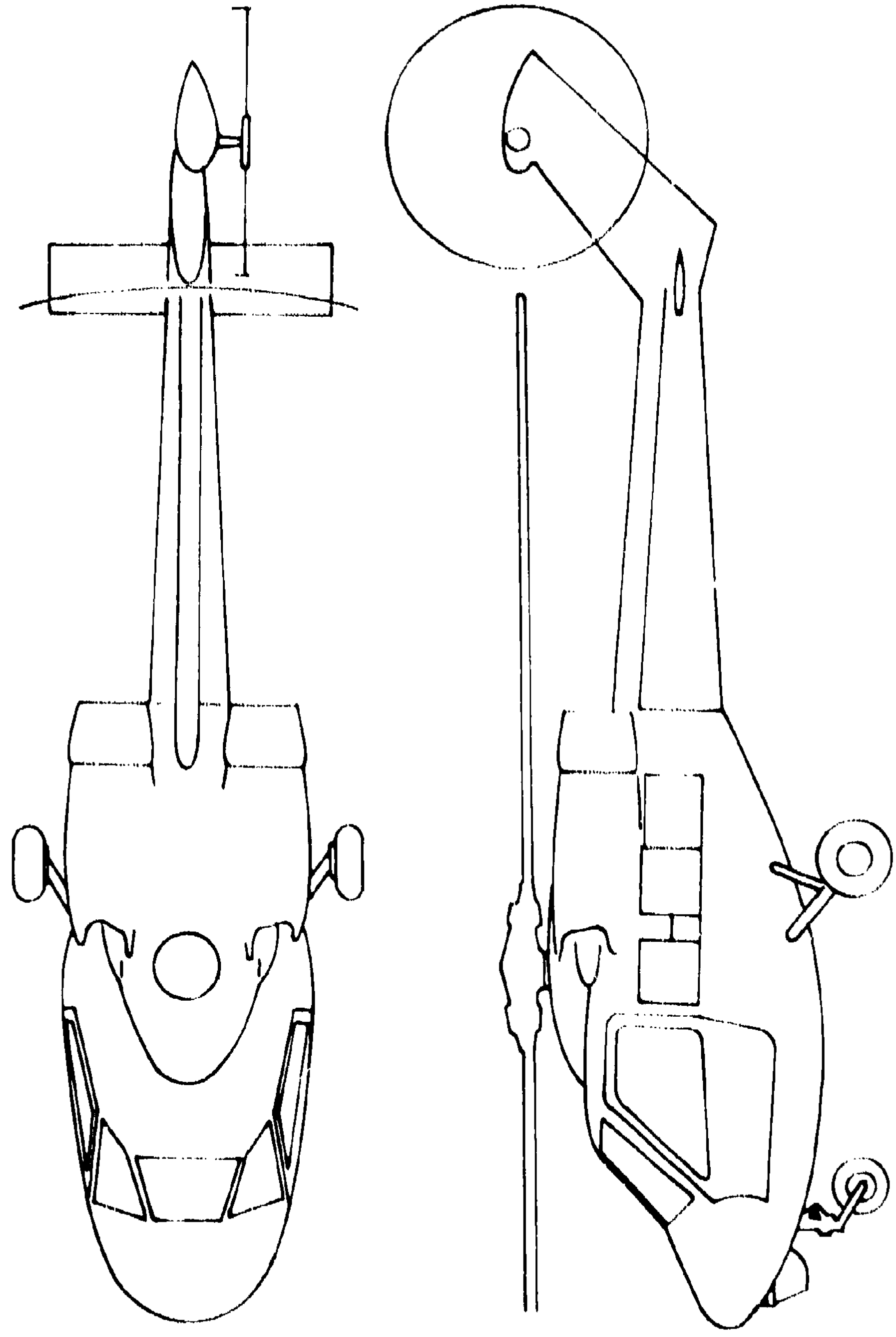

Figure 3. General arrangement of the baseline helicopter.

ACOUSTICAL ANALYSIS

PREDICTED NOISE SIGNATURES

The geometry used in predicting the aircraft noise signatures is shown schematically in Figure 4. The aircraft was at 200 feet altitude above sea level and a ground range of 1000 feet from the point of prediction. Airspeeds investigated were 0 (hover), 80, 120, and 150 knots. Surface wind velocity was zero, temperature was 60°F, and relative humidity was 70 percent.

Noise signatures of the various tip speed configurations were predicted using the noise computer program developed in References 5 and 6. NASA-Langley performed the computer analysis using their Theoretical Rotor Analysis Modeling Program (TRAMP), which incorporates the referenced procedures, Fourier analyzes the results, and generates a 1/3 octave band noise spectrum. The input data used in TRAMP was taken from Table 1 and the flight condition geometry shown in Figure 4. Typical output, for example, is the 1/3 octave band spectra shown in Table 2, which was derived for the 90 percent configuration.

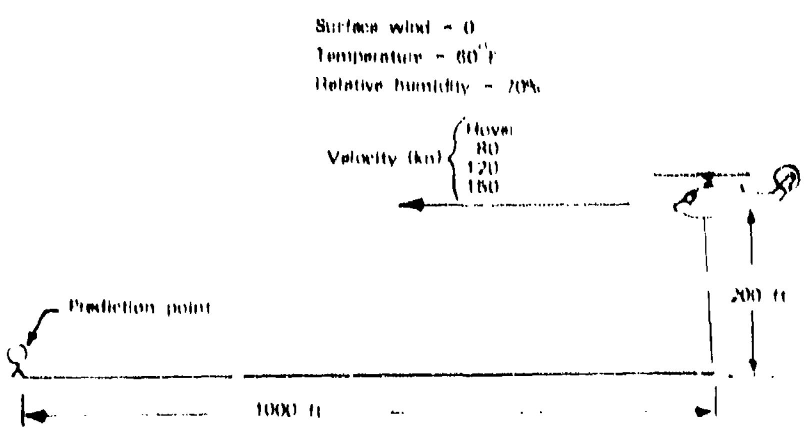

Figure 4. Noise prediction geometry.

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[5]Johnson, H. Kevin, *Development of a Technique for Realistic Prediction and Electronic Synthesis of Helicopter Rotor Noise*, Rochester Applied Science Associates, Inc., USAAMRDL TR 73-8, Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, March 1973, AD 759955.

[6]White, Richard P., Jr., *V/STOL Rotor and Propeller Noise – Its Prediction and Analysis of Its Aural Characteristics*, AIAA Paper No. 75-452, RASA Division of Systems Research Laboratories, Inc., Rochester, New York, 1975.

TABLE 2. 90% ROTOR TIP SPEED CONFIGURATION SOUND PRESSURE LEVELS

(1000-ft Ground Range, 200-ft Altitude)

1/3 Octave band	Hover			80 Knots			120 Knots			150 Knots		
	Main rotor	Tail rotor	Main + tail	Main rotor	Tail rotor	Main + tail	Main rotor	Tail rotor	Main + tail	Main rotor	Tail rotor	Main + tail
13	34.65	6.73	34.65	27.38	3.45	27.38	29.23	10.76	29.23	33.98	11.46	33.98
16	29.87	0	29.87	23.95	8.96	23.95	24.49	9.37	24.49	29.33	22.08	29.33
20	43.33	0	43.33	24.51	0	24.51	29.81	8.15	29.81	34.68	12.15	34.68
25	69.97	0	69.97	61.04	19.92	61.04	57.34	15.05	57.34	50.22	18.22	50.22
32	36.09	0	36.09	55.24	8.42	55.24	62.56	14.13	62.56	68.61	26.29	68.61
40	21.48	0	21.48	29.79	0	29.79	37.17	0	37.17	36.83	2.95	36.83
50	54.49	3.68	54.49	47.39	25.35	47.42	47.54	15.89	47.54	43.83	19.93	43.85
63	29.42	0	29.42	43.31	7.52	43.31	64.19	19.59	64.19	70.88	19.02	70.88
79	38.22	0	38.22	53.08	24.35	53.09	57.86	28.18	57.86	44.48	5.50	44.48
100	22.69	17.18	23.77	42.25	11.08	42.25	59.20	22.10	59.20	67.92	22.79	67.92
126	11.81	58.88	58.88	47.65	53.49	54.50	53.84	37.19	53.93	59.87	35.68	59.89
158	51.06	0	51.06	48.61	13.83	48.61	50.40	57.07	57.92	52.87	67.14	67.30
200	57.33	8.00	57.33	54.99	24.88	54.99	51.19	22.51	51.20	57.73	36.39	57.76
251	54.34	41.58	54.56	53.76	40.23	53.95	54.05	31.12	54.07	50.09	29.04	50.12
316	55.18	16.70	55.18	53.15	18.24	53.15	51.97	44.45	52.68	56.25	58.04	60.25
398	56.83	22.26	56.83	55.88	24.91	55.88	51.95	37.80	52.11	51.88	23.90	51.89
501	63.01	29.36	63.01	62.21	25.05	62.21	60.08	35.31	60.09	57.27	53.83	58.89
631	66.01	33.82	66.02	64.80	32.05	64.80	65.01	38.06	65.02	64.27	55.34	64.79
794	65.19	32.71	65.20	64.67	31.56	64.67	63.64	42.85	63.68	65.53	52.63	65.75
1000	57.77	29.26	57.78	57.86	31.54	57.87	59.91	39.77	59.95	58.89	47.59	59.20
1259	59.97	29.40	59.97	58.71	31.95	58.72	59.36	35.10	59.38	58.52	44.23	58.68
1585	29.11	36.01	36.82	59.80	35.64	59.82	60.47	41.50	60.52	61.32	49.61	61.52
1995	20.30	33.39	33.60	57.05	24.04	57.05	58.11	31.19	58.12	57.13	40.66	57.23
2512	23.31	35.22	35.49	38.06	25.63	38.30	55.65	32.17	55.67	56.36	38.12	56.42
3162	27.99	34.15	35.09	31.03	19.89	31.35	49.43	29.28	49.47	55.62	37.85	55.69
3981	32.01	24.07	32.66	32.37	16.97	32.49	38.87	26.13	39.10	49.01	37.88	49.33
5012	34.64	22.77	34.91	35.23	17.09	35.30	37.71	22.89	37.85	41.44	34.68	42.27
6310	25.58	0	25.58	18.22	0	18.22	19.15	0	19.15	23.26	19.62	24.82
OA	73.60	59.07	73.75	71.34	53.91	71.42	72.58	57.86	72.72	75.95	68.32	76.64

PREDICTED DETECTION DISTANCES

The computer program used for predicting helicopter detection distances is described in Reference 7. The 1/3 octave band noise signatures generated in TRAMP were used as input to the detection program. The acoustic signature of each helicopter configuration was "distance increased" by the detection program to the point where it would be masked by an ambient noise level. These calculated distances represented the maximum slant range (hypotenuse of the ground range/altitude triangle) at which each configuration could be aurally detected by an observer. Background ambient noise levels used in these predictions represent low, medium, and high intensity conflict situations (taken from Reference 8) and are shown in Figure 5. The terrain used was relatively flat and covered with grass about 6 to 8 inches tall. A sample listing of the input data for the 90-percent example case configuration is shown in Table 3.

An example of output from the detection program is shown in Table 4. The frequency in octave bands is printed along the ordinate, and the detection distance for each octave band is shown along the abscissa. The probability of detection is shown at different percentile levels as indicated by the symbols D, +, and X. Throughout this program the 50 percent observer points were used, as indicated by the symbol X. This means that all detection distances were established at the point where half of the listening observers would have cumulatively registered a detection. Table 4 shows this detection point occurring at 2800 feet slant range simultaneously in the 500 Hz (355 to 707 Hz) and 1000 Hz (707 to 1414 Hz) octave bands. Table 5 summarizes the results of all the tip speed design configurations used in this study. Each tip speed configuration is broken down into each of the parameters examined, along with the resulting values.

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[7] Abrahamson, A. Louis, *Correlation of Actual and Analytical Helicopter Aural Detection Criteria*, Volume I, Wyle Laboratories, USAAMRDL TR 74-102A, Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, January 1975, AD C001209L.

[8] Blewitt, Stephen J., et al, (C) *Analysis of the Effects of Aural-Detection Range on Helicopter Operations* (U), Boeing Vertol Company, USAAMRDL TR 73-80, Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, March 1974, AD 530250L.

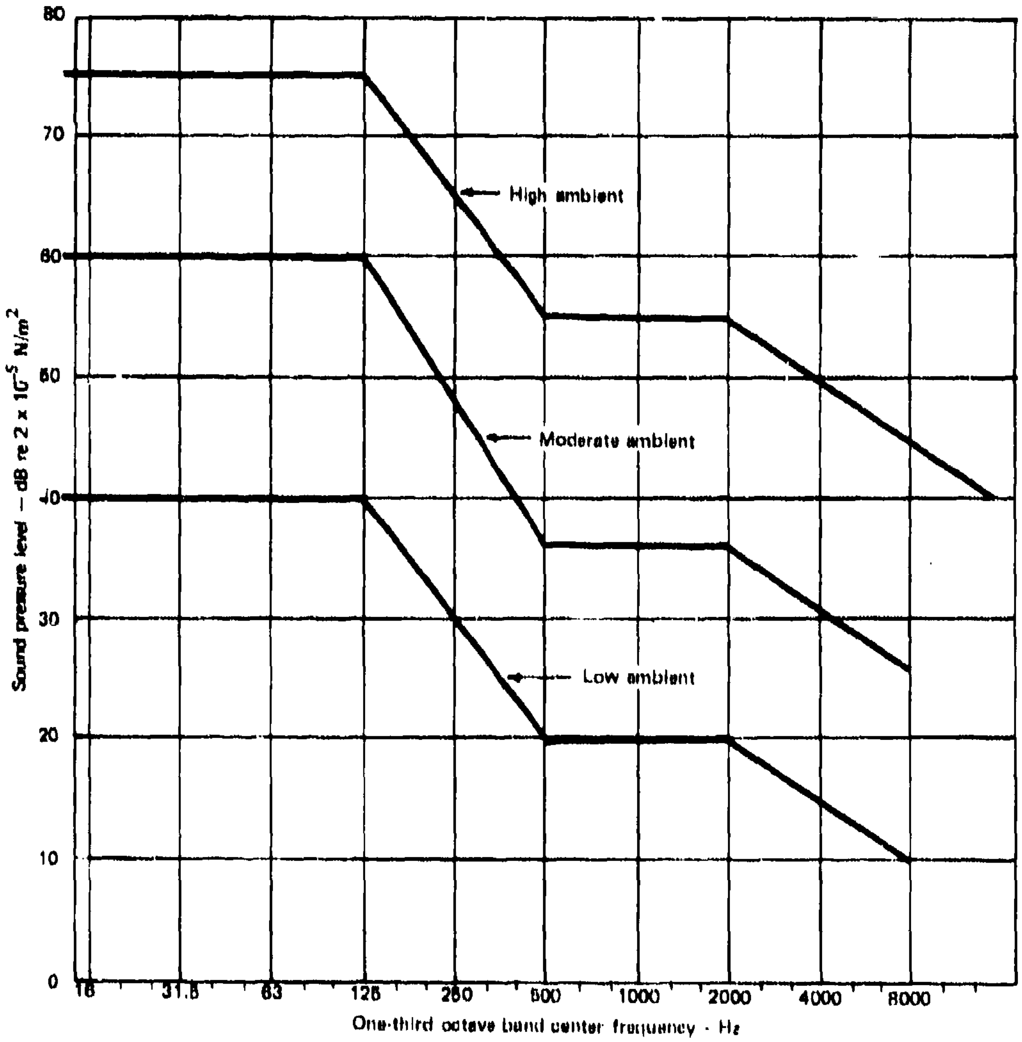

Figure 5. Ambient noise levels.

TABLE 3. HELICOPTER DETECTION DISTANCE PROGRAM INPUT DATA

```
 159 14.9633
111
90% MAIN ROTOR 1000FT OR 200FT ALT 80KTS                  OASPL = 71.39 DB
  30
  27.38    23.95    24.51    61.00    55.24    29.79    47.39    43.31    53.08    42.25
  47.65    49.61    56.99    53.76    53.15    55.58    62.21    60.80    64.67    57.86
  59.79    59.80    57.95    38.06    31.03    32.37    35.23    18.22   -99.00   -99.00
   0
  60.0    9.22
1 0.0        0.0
  200.0  253.35
  1019.8
   3
ONE THIRD OCTAVE LOW AMBIENT FIG 15 USAAMRDL TR 73-80
  30
  40.0     40.0     40.0     40.0     40.0     40.0     40.0     40.0     40.0     40.0
  40.0     37.0     33.0     30.0     27.0     23.0     20.0     20.0     20.0     20.0
  23.0     23.0     20.0     18.0     16.0     15.0     13.0     11.0     10.0     10.0
  60.0    9.22
1 0.0        0.0
  200.0  253.35
ONE THIRD OCTAVE MODERATE AMBIENT FIG 15 USAAMRDL TR 73-80
  30
  60.0     60.0     60.0     60.0     60.0     60.0     60.0     60.0     60.0     60.0
  60.0     55.0     51.0     48.0     43.0     40.0     36.0     36.0     36.0     36.0
  35.0     35.0     36.0     34.0     32.0     31.0     29.0     28.0     26.0     24.0
  50.0    9.22
1 0.0        0.0
  200.0  253.35
ONE THIRD OCTAVE HIGH AMBIENT FIG 15 USAAMRDL TR 73-80
  30
  75.0     75.0     75.0     75.0     75.0     75.0     75.0     75.0     75.0     75.0
  75.0     71.0     68.0     65.0     61.0     58.0     55.0     55.0     55.0     55.0
  55.0     55.0     55.0     53.0     51.0     50.0     48.0     46.0     45.0     43.0
  65.0    9.22
1 0.0        0.0
  200.0  253.35
```

TABLE 4. SLANT RANGE DETECTION DISTANCE

```
HELO IDENT      9?% MAIN ROTOR TARGET OR POINT ALT [illegible]          TASBL = 7?.?? DB
TEMP=     8?.?? DEGREES F          HUMIDITY= 9.22 GM/METER
SURFACE IS SMOOTH                  WIND VELOCITY=   0.0        DIRECTION =     0.0
ALTITUDE=    200.00 FEET           VELOCITY=   253.35 FT/SEC
SLANT RANGE   1?1?.?? FEET         DETECTED RANGE   15?2.1? FEET

AMBIENT IDENT      THE THIRD OCTAVE HIGH AMBIENT FIG 15 USARMRDL TR 73-??
TEMP=     6?.?? DEGREES F          HUMIDITY=    9.22 GM/METER
SURFACE IS SMOOTH                  WIND VELOCITY=   0.0        DIRECTION =     0.0
ALTITUDE=    200.00 FEET           VELOCITY=   253.35 FT/SEC

        DETECTABILITY SUMMARY                  PROBABILITY OF DETECTION FROM 68 TO 100 PERCENT  = O
                                                                             50 TO  68 PERCENT  = +
                                                                             ABOUT 50 PERCENT   = X
                                                                             32 TO  50 PERCENT  = -
        RANGE IN HUNDRED FEET                                                 0 TO  32 PERCENT  = BLANK
```

FREQ	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60
0- 11																														
11- 22																														
22- 44	X																													
44- 88	X																													
88- 177	+																													
177- 354	O	O	O	+	X																									
354- 707	O	O	O	O	O	O	O	O	O	O	O	+	+	X	-	-	-													
707- 1414	O	O	O	O	O	O	O	O	O	O	O	+	+	X	-	-														
1414- 2828	O	O	O	O	O	O	O	+	+	X	-																			
2828- 5657	O	+																												
5657-11314																														

TABLE 5. TIP SPEED DESIGN CONFIGURATIONS

% Tip Speed		Hover			80 Knots			120 Knots			150 Knots		
		Main rotor	Tail rotor	Main + tail	Main rotor	Tail rotor	Main + tail	Main rotor	Tail rotor	Main + tail	Main rotor	Tail rotor	Main + tail
80	D.D. low amb - Kft	10.8	4.2	10.8	10.2	5.4	10.4	11.2	5.0	11.2	11.4	8.0	11.4
	Octave band(s) C.F. - Hz	500	125 & 500	500	500	500 & 1000	500	500	500	500	500	250	500
	D.D. moderate amb - Kft	6.4	1.8	6.4	6.0	2.4	6.0	6.6	2.2	6.6	6.8	3.2	6.8
	Octave band(s) C.F. - Hz	500	1000 & 2000	500	500	500 & 1000	500	500	500 & 1000	500	500 & 1000	250 & 1000	500 & 1000
	D.D. high amb - Kft	2.4	0.4	2.4	2.2	0.6	2.2	2.6	0.4	2.6	2.8	1.0	2.8
	Octave band(s) C.F. - Hz	500	1000 & 2000	500	500 & 1000	500 & 1000	500 & 1000	500 & 1000	500 & 2000	500 & 1000	500 & 1000	1000	500 & 1000
	V_{AT} - f/s	560			695			762			813		
	M_{AT} - Unity	.502			.623			.683			.729		
	Predicted OASPL - dB	68.8	52.1	69.0	67.0	56.3	67.5	73.9	59.3	74.0	79.7	70.0	80.1
90	D.D. low amb - Kft	12.2	5.0	12.2	11.8	3.6	11.8	11.8	5.2	11.8	11.6	9.0	11.6
	Octave band(s) C.F. - Hz	500	125	500	500	125	500	500	125 & 1000	500	500	500	500
	D.D. moderate amb - Kft	7.4	1.4	7.4	7.2	1.4	7.2	7.2	2.4	7.2	7.0	4.8	7.2
	Octave band(s) C.F. - Hz	500	2000	500	500	2000	500	500	1000	500	500 & 1000	500	500
	D.D. high amb - Kft	3.0	0.4	3.0	2.8	0.2	2.8	2.8	0.6	2.8	2.8	1.6	3.0
	Octave band(s) C.F. - Hz	500 & 1000	2000	500	500 & 1000	125 & 500	500	500 & 1000	1000	500 & 1000	500 & 1000	500	500 & 1000
	V_{AT} - f/s	630			765			833			883		
	M_{AT} - Unity	.564			.685			.746			.791		
	Predicted OASPL - dB	73.6	59.1	73.8	71.3	53.9	71.4	72.6	57.9	72.7	76.0	62.3	76.6
95	D.D. low amb - Kft	12.2	5.0	12.2	12.0	4.4	12.0	11.6	7.0	11.6	10.6	10.8	11.4
	Octave band(s) C.F. - Hz	500	125	500	500	125, 250, & 1000	500	500	500	500	1000	500	500
	D.D. moderate amb - Kft	7.6	1.2	7.6	7.4	1.3	7.4	7.0	3.4	7.0	6.6	6.2	7.0
	Octave band(s) C.F. - Hz	500	125 & 2000	500	500	500 & 1000	500	500 & 1000	500	500 & 1000	1000	500	500
	D.D. high amb - Kft	3.2	0.2	3.2	3.0	0.4	3.0	2.8	1.0	2.8	2.8	2.2	2.8
	Octave band(s) C.F. - Hz	500	1000	500	500 & 1000	1000	500 & 1000	500 & 1000	500	500 & 1000	1000	500	500 & 1000
	V_{AT} - f/s	665			800			868			919		
	M_{AT} - Unity	.596			.717			.777			.832		
	Predicted OASPL - dB	75.0	60.0	75.0	72.7	56.1	72.8	73.1	59.4	73.3	76.5	71.5	77.7

TABLE 5 - Continued.

% Tip Speed		Hover Main rotor	Hover Tail rotor	Hover Main + tail	80 Knots Main rotor	80 Knots Tail rotor	80 Knots Main + tail	120 Knots Main rotor	120 Knots Tail rotor	120 Knots Main + tail	150 Knots Main rotor	150 Knots Tail rotor	150 Knots Main + tail
100	D.D. low amb - Kft	10.8	4.6	10.8	12.0	5.0	12.0	11.2	9.4	11.4	10.4	12.4	12.6
	Octave band(s) C.F. - Hz	500	125	500	500	500	500	500 & 1000	500	500	500	500	500
	D.D. moderate amb - Kft	6.4	1.2	6.4	7.4	2.0	7.4	7.0	5.0	7.0	6.0	7.4	7.6
	Octave band(s) C.F. - Hz	500	125 & 250	500	500	500	500	1000	500	500 & 1000	500	500	500
	D.D. high amb - Kft	2.4	0.2	2.4	3.0	0.4	3.0	3.0	1.6	3.0	2.2	3.0	3.2
	Octave band(s) C.F. - Hz	500 & 1000	125, 250,& 500	500 & 1000	500 & 1000	500 & 1000	500 & 1000	1000	500	1000	500, 1000, & 2000	500 & 1000	1000
	V_{AT} - f/s	700			835			903			953		
	M_{AT} - Unity	.627			.748			.809			.854		
	Predicted OASPL - dB	74.6	59.6	74.7	76.9	54.9	77.0	76.0	65.1	76.4	78.6	74.0	79.9
105	D.D. low amb - Kft	11.4	6.2	11.4	11.8	7.4	11.8	10.4	11.0	11.4	9.6	13.2	13.4
	Octave band(s) C.F. - Hz	500	125	500	500	500	500	500 & 1000	500	500	500	500	500
	D.D. moderate amb - Kft	6.8	1.8	6.8	7.2	3.6	7.2	6.2	6.2	6.6	5.4	8.6	8.6
	Octave band(s) C.F. - Hz	500 & 1000	125 & 250	500 & 1000	500 & 1000	500	500 & 1000	500 & 1000	500	500 & 1000	500 & 1000	500	500
	D.D. high amb - Kft	2.8	0.4	2.8	3.0	1.0	3.0	2.4	2.2	2.8	2.0	3.8	3.8
	Octave band(s) C.F. - Hz	500 & 1000	125, 250, & 1000	500 & 1000	500 & 1000	500	500 & 1000	500 & 1000	500 & 1000	1000	1000 & 2000	500 & 1000	500 & 1000
	V_{AT} - f/s	735			870			938			988		
	M_{AT} - Unity	.658			.779			.840			.885		
	Predicted OASPL - dB	78.3	61.2	78.4	76.9	60.0	77.0	77.7	70.5	78.5	83.0	76.1	83.8

D.D. = Detection distance
C.F. = Center frequency of detectable band
V_{AT} = Advancing tip velocity
M_{AT} = Advancing tip Mach number

RESULTS

OVERALL SOUND PRESSURE LEVELS

The results of the acoustical analysis for the baseline and alternate configurations are shown in Figure 6. Overall sound pressure level (OASPL) is shown as a function of tip speed, both separately and cumulatively for the main and tail rotors. Figures 6(a) through 6(d) present this data for each of four flight speed conditions.

In the hover condition (Figure 6(a)), the main rotor dominated OASPL for all configurations and increased linearly in noise level as tip speed configurations increased. Although quieter than the main rotor, the tail rotor also showed the linear trend of increased noise with increased tip speed.

At the 80-knot condition (Figure 6(b)), the main rotor again produced a linear noise trend with increased rotor speed aircraft design, and again dominated the cumulative OASPL. The tail rotor sound levels were too low to contribute to the main rotor OASPL; however, the tail rotor of the 90-percent configuration was shown to be optimum, as indicated by the "bucket" (minimum point) in the tail rotor curve.

At both the 120- and 150-knot conditions (Figure 6(c) and (d)), the 90-percent configuration main and tail rotor OASPLs were optimum (minimum). Also, at these two flight speeds, the tail rotor noise became louder with increasing tip speed, as shown by the increasing slope of the tail rotor noise curve. In Figure 6(d) (150 knots), it is seen that the tail rotor noise levels for the 90 through 105 percent configurations raised the total rotor system noise levels by only 1 dB.

The OASPL results for the total rotor system (main plus tail rotors) show that at hover and 80-knot flight speed, no particular rotor tip speed configuration was optimum; rather, the lower the tip speed, the lower the OASPL. Also, at these two flight speeds, the maximum change in OASPL for all tip speed designs was 9.5 dB (OASPL of 105 percent minus OASPL of 80 percent tip speed). Further, the linearity of these two curves shows that at the hover and 80-knot conditions, an aircraft meeting PMP requirements resulted in a 0.054 dB noise reduction per fps rotor tip speed reduction (i.e., $\frac{9.5\ \text{dB}}{735 - 560\ \text{fps}}$).

At 120 and 150 knots, the 90-percent configuration was optimum in terms of OASPL. The OASPL differences between the optimized configuration (90 percent) and the maximum configuration (105 percent) were 6 and 7 dB respectively for the 120- and 150-knot conditions.

Looking back at the total rotor noise of the hover and 80-knot conditions (Figure 6(a) and (b)), the differences between the 90 and 105 percent configurations were 5 and 6 dB. Thus, considering all four flight speeds, it is seen that in terms of total rotor system OASPL, the 90-percent configuration does offer an average noise optimization of 6 dB.

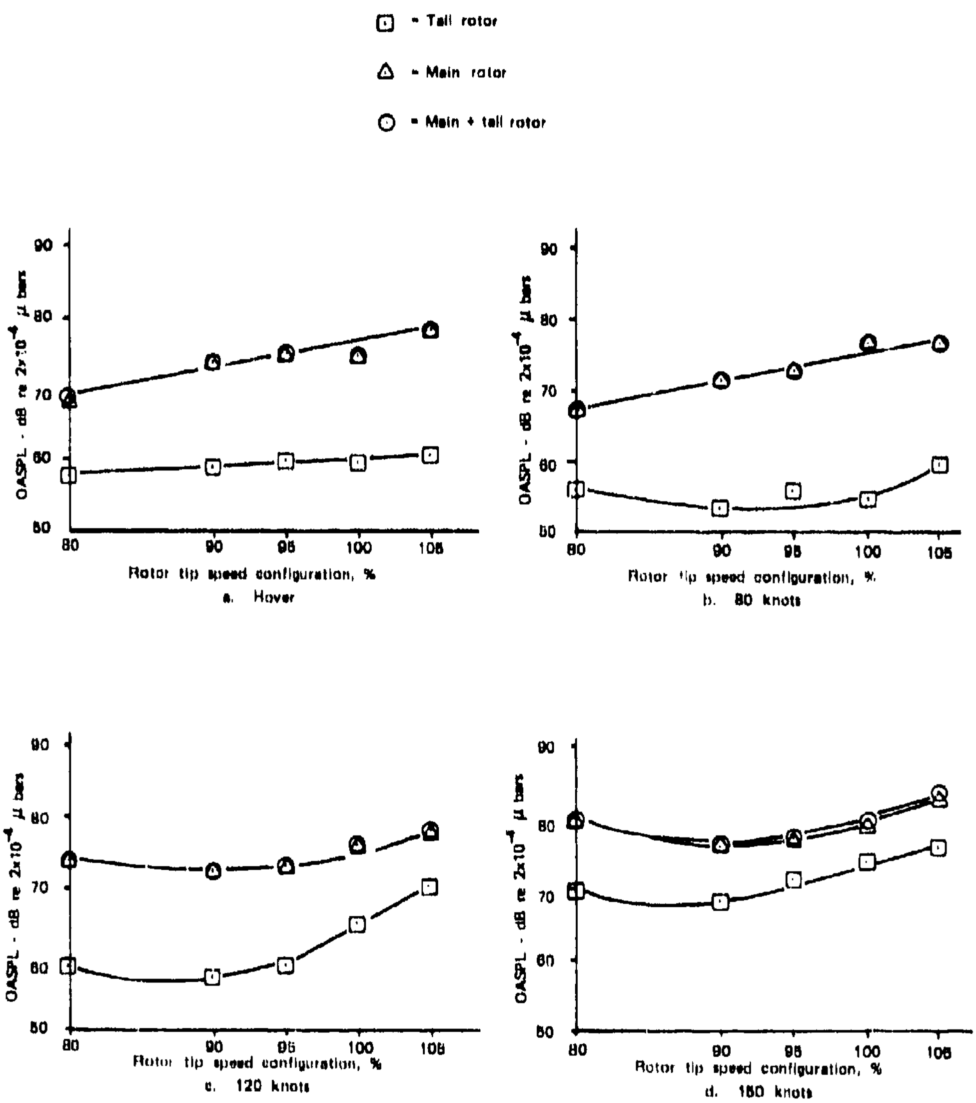

Figure 6. Predicted overall sound pressure levels for various rotor tip speed configurations.

DETECTION DISTANCE

The aural detection distances for the various configurations are shown in Figures 7, 8, and 9 and were based on the low, moderate, and high ambient background noise curves of Figure 4.

In the hover condition, detectability is established by the main rotor noise (Figure 7(a)). This upper curve with its two minimum points shows that either the 80-percent or the 100-percent tip speed configuration is optimum in hover. The trend of the tail rotor hover condition curve is generally toward greater detection distance as a function of increased tip speed. The combined signature of main plus tail rotor noise did not increase detection distance, because the tail rotor's 1/3 octave noise levels were significantly below those of the main rotor.

The 80-knot condition shows the main rotor dominating the detection distance for all configurations (Figure 7(b)). At this speed, the main rotor of the 80-percent configuration is detectable around 10,000 feet while the other configurations may be detected at approximately 12,000 feet. The tail rotor in this figure was much less detectable than the main rotor and produced an optimum point for the 90-percent configuration. Again it is seen that the combined aircraft signature of main plus tail rotor did not increase detection distance beyond that already established by the main rotor.

In the 120- and 150-knot conditions (Figure 7(c) and (d)), the main rotor detection distances generally did not increase with the increases in tip speed; rather, at 100 percent and 105 percent, detection distance decreased. On the other hand, the tail rotor grew progressively more detectable. In these two highest speed conditions, the tail rotor detection curve rose above the main rotor curve. The main plus tail rotor curve of Figure 7(c) and (d) shows that the tail rotor, from about the 95-percent to the 105-percent configurations, increased detection distance both as a function of increased tip speed and increased flight speed. In Figure 7(d) (150 knots) the tail rotor noise, when added to the main rotor, increased detectability of the 105 percent configuration from 9600 to 13,400 feet.

Generally, Figure 7 shows that overall detectability of the various tip speed configurations did not change very much. The detection distance at hover, 80 knots, and 120 knots for all tip speed configurations fell within a 10,200- to 12,000-foot spread (18-percent increase). At 150 knots, however, the tail rotor dominated noise and expanded the overall detectability spread out to 13,400 feet (31-percent increase). This information tells the designer that at high speed (150 knots), any tail rotor configurations beyond 90 percent would be unacceptable due to increased detectability. Further, it indicates that the tail rotor should be acoustically redesigned (quietened) so as not to exceed the main rotor detection distance.

In summary, the choice of an optimized tip speed configuration in terms of minimum detectability required consideration of several factors: (1) the data results did not produce a family of concave curves with a low midpoint to indicate an optimum tip speed; (2) the main plus tail rotor curves of Figure 7 tended to be convex, resulting in favorable tip speed configurations occurring at the curve end points of either 80 percent or 100 to 105 percent; and (3) the 150-knot condition was an exception due to the pronounced effect of the tail rotor. Therefore, an optimized tip speed configuration chosen on an average basis for minimum detection distance was 100 percent. This 100 percent

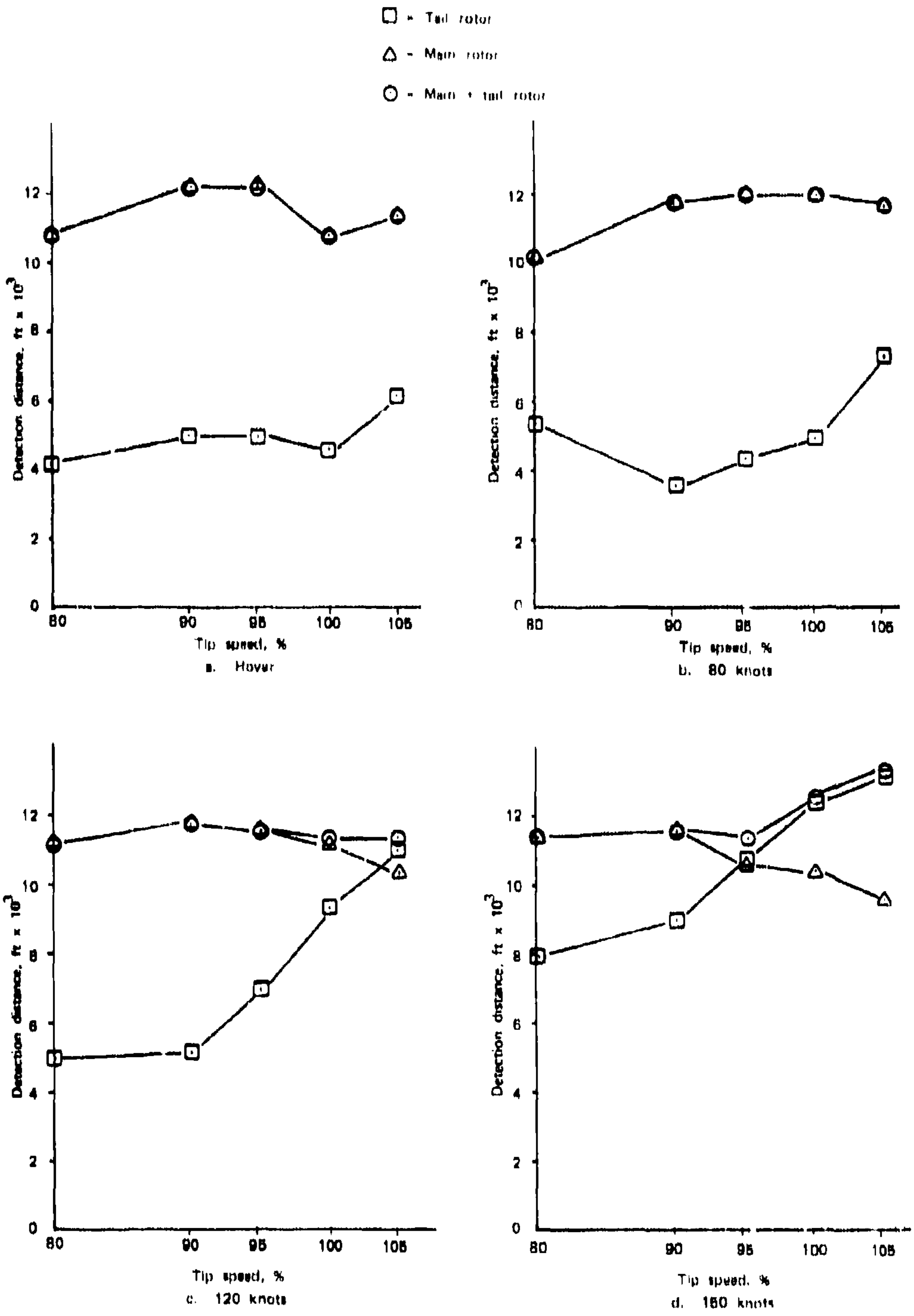

Figure 7. Detection distances with low ambient noise background.

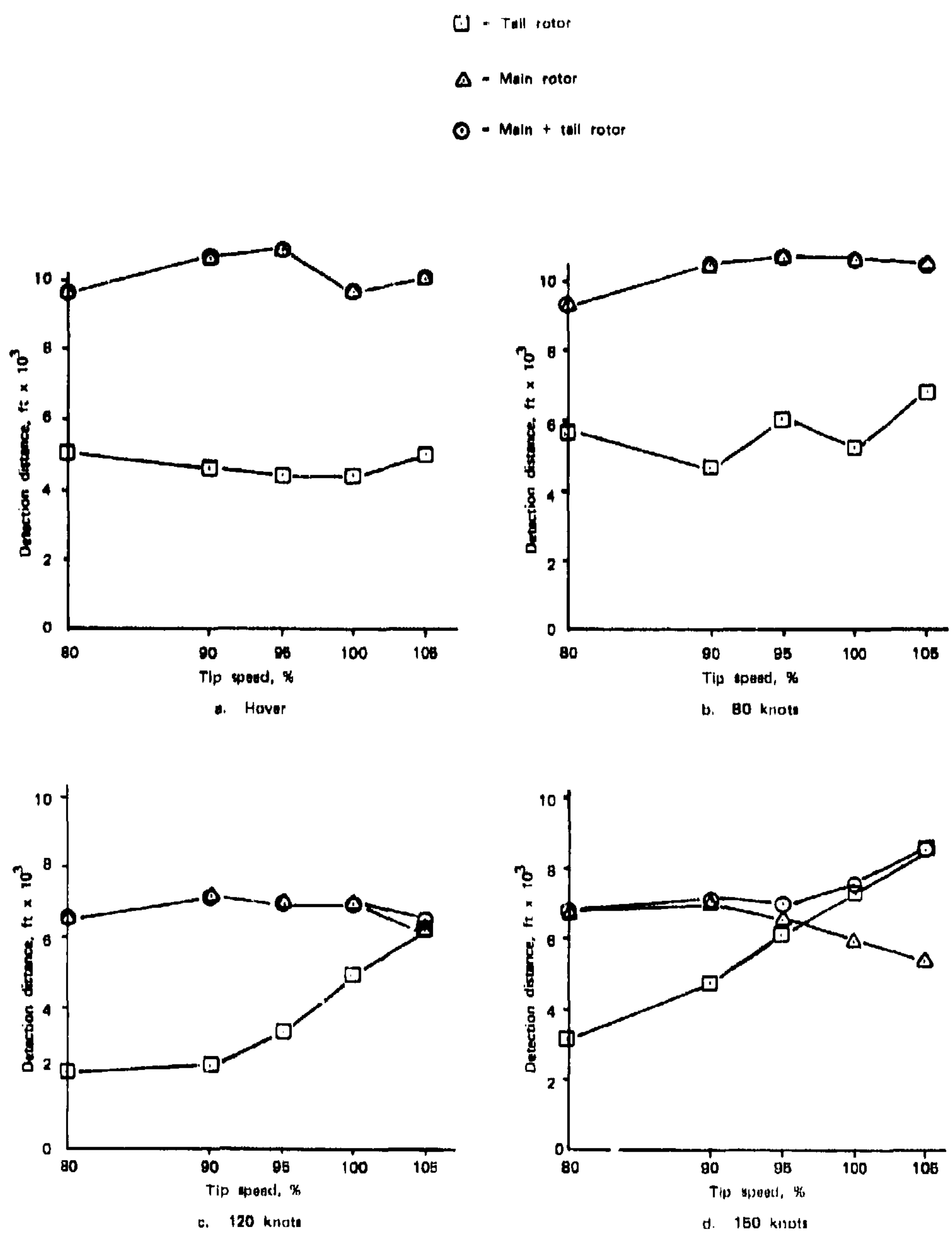

Figure 8. Detection distances with moderate ambient noise background.

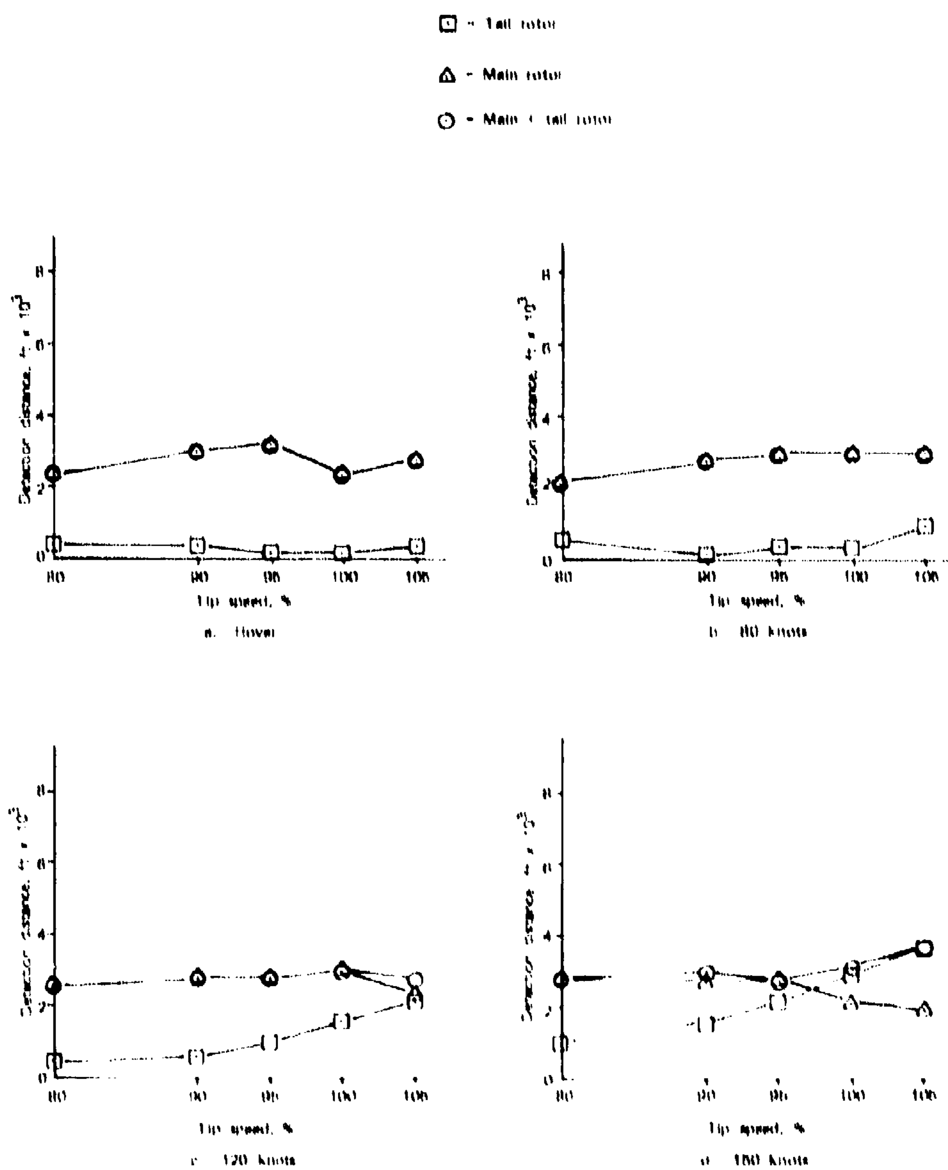

Figure 9. Detection distances with high ambient noise background.

tip speed configuration represents a best choice between the curves of Figure 7 and the lower component weight values listed in Table 1.

Figures 8 and 9 show detectability trends of the various configurations under moderate and high background noise levels. The trending curves are similar to those of Figure 7 but show less inflections as ambient noise levels increase. The average maximum detection distances decreased from 12,000 to 7,000 to 3,000 feet as the ambient noise increased from low to moderate to high in Figures 7, 8, and 9 respectively. Increased levels of ambient noise reduced detectability by a factor of four.

OASPL AND DETECTION DISTANCE COMPARISON

The maximum change in OASPL for any one flight condition was 9.5 dB (Figure 6(b)). This could lead one to roughly estimate that detection distance would be doubled almost twice (each 6-dB increase in sound pressure level doubles detection distance when only free-field spherical spreading is considered).

Examination of the computed change in detection distance of this same flight condition (Figure 7(b)) shows that only a change from 10,400 to 11,800 feet has occurred. The reason for this small change is that detectability computations include a number of factors such as the listener's capability, the noise spectral distribution of both the source and the listener's ambient, and the total atmospheric attenuation effects between the source and the listener. OASPL, on the other hand, is a single value summation of noise spectra and is not dependent on spectral distribution. Because of these differences, OASPL is not a reliable means of equating a single value of noise level to a measure of detection distance.

In hover and the 80-knot flight speed, OASPL increased almost linearly with increased tip speed while detection distance reached maximum at the 90-percent configuration and did not significantly change thereafter. At the latter two flight speeds of 120 and 150 knots, OASPL optimized at 90 percent. Detectability, however, optimized at the 100-percent tip speed design. Also, the increased detectability of the tail rotor design was not revealed in the OASPL trends. The tail rotor was found to dominate detectability beyond the 90-percent configuration for the 120- and 150-knot conditions. This provides a valid reason to further investigate the tail rotor to determine what measures can be taken to bring its detectability down to the maximum established by the main rotor.

EFFECT OF GROSS WEIGHT ON NOISE AND DETECTION

As the various helicopter configurations incrementally decreased in tip speed (while still maintaining PMP), the net effect was an increase in gross aircraft weight. Reasons for the weight increase were:

- As rotor tip speed was reduced, solidity increased approximately as the inverse of the ratio of the square of the tip speeds. For a fixed disc loading, this resulted in an increase in blade chord, which further resulted in an increase in rotor profile drag and therefore more power was required.

- The increase in blade chord, together with the reduction in tip speed, resulted in increased rotor and hub weight.

- The increased power required resulted in larger engines, with an increase in the weight of the engines and their ancillary equipment (intake and exhaust systems, engine mounts, starters, and fuel systems). The increased power, together with the reduced rotor rpm, resulted in an increase in the weight of the drive system.

- The increase in the weight of the structure, equipment, and mission fuel required the size of the helicopter to increase in order to retain the required payload capability and mission endurance. A 20-percent reduction in tip speed resulted in a helicopter with a gross weight increase of about 10 percent. Weight increase is summarized in Table 1.

Over the range of tip speeds considered, increasing tip speed reversed the above trends. A 5-percent increase in tip speed to 735 fps (105 percent configuration) resulted in a gross weight reduction of about 1 percent. Increasing tip speed beyond this range would probably result in detrimental tip Mach number effects. This in turn would increase gross weight because of propulsion system growth.

To show the trending effect of gross weight on noise and detection, the abscissas of Figures 6 through 9 could be relabled with the Table 1 gross weight values corresponding to the tip speeds; for example, the 80-percent configuration corresponds to 6318 pounds and the 90-percent configuration corresponds to 5922 pounds, etc. The same observations made to arrive at the optimum tip speed configurations apply to gross weight, i.e., the optimum gross weight in terms of OASPL was 5922 pounds (90-percent tip speed); for detection distance, 5708 pounds (100-percent tip speed).

TACTICAL AND SURVIVABILITY COMMENTS

Reference 8 shows that survivability increases when firing time (the number of rounds fired) is reduced. Further, it shows that there is no survivability improvement when the new reduced detection distance is still greater than the maximum effective firing range of the weapon under consideration. With the knowledge of maximum effective weapon range and the target's aural detection distance, one can easily estimate where payoff in increased survivability will begin. For example, decreasing helicopter detectability from 12,600 to 10,400 feet (Figure 7(d), 100-percent configuration) would have no beneficial effect against an aurally detected gun threat with only a 9000-foot effective range. In moderate and high noise backgrounds, some survivability payoff could be expected due to the decreased detection distance within the effective gun range (Figures 8(d) and 9(d)). A survivability analysis is beyond the scope of this report, since this type of analysis includes such factors as gun ready time, projectile flight path, and ballistic dispersion, as covered in Reference 8.

CONCLUSIONS

Based on the results of this effort, it is concluded that:

1. Of the five helicopter configurations investigated, the 90-percent rotor tip speed configuration is the optimum design in terms of overall sound pressure level.

2. The 100-percent configuration (700 fps) is the most suitable design based on its better overall detectability and component weight characteristics.

3. Overall sound pressure level values are not reliable as a means of detectability.

4. Increased ambient noise levels had the greatest effect on reducing detection distance.

5. The methodology used in this investigation can also be used to determine the noise reductions and detectability benefits gained by varying other parameters such as blade numbers, rotor airfoils, and main and tail rotor rpm ratios.

RECOMMENDATIONS

Based on the conclusions made during this analysis, it is recommended that:

1. The 100-percent configuration tail rotor design be investigated further to optimize its noise characteristics so that it will not be the source of detection in the high forward speed condition. Reduced tip speed for the tail rotor is a recommended approach.

2. In choosing a rotor system design for minimized acoustic detection, rotor noise levels and listener background conditions be predicted, preferably in 1/3 octave band spectra. When combined with attenuation factors and listener capability, this data will provide a reasonable basis for determining detectability. Furthermore, individual noise contributions which establish detectability can be traced and modified for quieter, less detectable aircraft.

3. OASPL values not be equated to detectability.

4. A noise/detectability analysis be performed in conjunction with performance design studies to select the best aircraft design to meet acoustic detectability requirements.

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APPENDIX A. PRIMARY MISSION PERFORMANCE REQUIREMENTS

The primary mission performance requirements of the ASH include the ability to attain:

- A 450-ft/min. vertical rate of climb from out-of-ground effect (OGE) hover, at 4000 ft pressure altitude (Hp), 95°F, using not more than 95 percent of installed intermediate rated power (IRP) under zero wind conditions.
- A cruise speed of 120 to 150 KTAS at 4000 ft Hp, 95°F, using not more than maximum continuous power (MCP).
- An endurance of not less than 2.5 hours based on the following segments at 4000 ft hp/95°F conditions:

  1. 8 minutes of ground idle power
  2. 30 minutes of hover OGE with zero wind
  3. 30 minutes of 40 KTAS
  4. 30 minutes at hover OGE with zero wind
  5. 22 minutes at MCP cruise speed or 150 KTAS, whichever is less
  6. 30 minutes fuel reserve at 120 KTAS

  Segments (1) through (5) are to be computed at primary mission gross weight. Segment (6) is to be computed at primary mission gross weight less fuel burned in segments (1) through (5).

- A minimum normal acceleration of 1.50g in a symmetrical pull-up from level unaccelerated flight at 130 KTAS.